CLAIMS

We claim:

1. A method in a computing system for controlling an electroplating process in which a sequence of workpieces are electroplated with a material each in an electroplating cycle, such controlling including designating, for each electroplated workpiece, currents supplied to each of a plurality of electroplating anodes, comprising:

constructing a Jacobian sensitivity matrix characterizing the effects on plated material thickness at each of a plurality of workpiece positions of varying the currents supplied each of the plurality of anodes;

receiving a specification of target plating material thickness at each of the plurality of workpiece positions;

applying the Jacobian sensitivity matrix to make a first determination of how a baseline set of anode currents should be varied to produce the specified target plating material thicknesses rather than baseline plating material thicknesses indicated to result from the baseline set of anode currents;

generating an indication to conduct a first electroplating cycle with respect to a first workpiece using a designated set of anode currents produced by varying the baseline set of anode currents in accordance with the first determination;

receiving measured plating material thicknesses thickness at each of the plurality of workpiece positions of the first workpiece;

applying the Jacobian sensitivity matrix to make a second determination of how the set of anode currents designated for the first electroplating cycle should be varied to produce the specified target plating material thicknesses rather than measured plating material thicknesses of the first workpiece; and

generating an indication to conduct a second electroplating cycle with respect to a second workpiece using a designated set of anode currents produced by varying the set of anode currents designated for the first electroplating cycle in accordance with the second determination.

2. The method of claim 1, further comprising:

receiving measured plating material thicknesses at each of the plurality of workpiece positions from the second electroplating cycle;

determining that the measured plating material thicknesses from the second electroplating cycle are within a specified tolerance of the specified target plating material thicknesses; and

in response to the determination, generating one or more indications to conduct a plurality of further electroplating cycles using the set of anode currents designated for the second electroplating cycle.

3. The method of claim 1, further comprising:

receiving measured plating material thicknesses at each of the plurality of workpiece positions from the second electroplating cycle;

applying the Jacobian sensitivity matrix to make a third determination of how the set of anode currents designated for the second electroplating cycle should be varied to produce the specified target plating material thicknesses rather than measured plating material thicknesses of the second workpiece; and

generating an indication to conduct a third electroplating cycle using a designated set of anode currents produced by varying the set of anode currents designated for the second electroplating cycle in accordance with the second determination.

4. The method of claim 1, further comprising:

before the first electroplating cycle, receiving measured seed layer thicknesses of the first workpiece at each of the plurality of workpiece positions; and

before the second electroplating cycle, receiving measured seed layer thicknesses of the second workpiece at each of the plurality of workpiece positions,

and wherein the second determination made by applying the Jacobian sensitivity matrix is a determination of how the set of anode currents designated for the first electroplating cycle should be varied to produce the specified target plating material thicknesses rather than measured plating material thicknesses of the first workpiece in light of the differences between the measured seed layer thicknesses of the first and second workpieces.

5. The method of claim 1 wherein the Jacobian sensitivity matrix is generated from a numerical model of the electroplating process.

6. The method of claim 1 wherein the Jacobian sensitivity matrix is generated from data obtained by operating the electroplating process.

7. The method of claim 1 wherein the baseline plating material thicknesses are generated from data obtained by simulating operation of the electroplating process using a numerical model of the electroplating process, the simulation using the baseline anode currents.

8. The method of claim 1 wherein the baseline plating material thicknesses are generated from data obtained by operating the electroplating process with the baseline anode currents.

9. A method in a computing system for providing closed-loop control of a process for applying a coating material to a series of workpieces to produce a coating layer of the coating material, comprising:

(a) receiving a coating profile specifying one or more attributes of the coating layer to be produced on the workpieces;

(b) designating a first set of coating parameters for use in coating a first workpiece;

(c) identifying a first set of discrepancies between attributes of the coating layer produced on the first workpiece using the first set of coating parameters and the attributes specified by the coating profile;

(d) determining a first set of modifications to the first set of coating parameters expected to reduce the identified first set of discrepancies;

(e) modifying the first set of coating parameters in accordance with the determined first set of modifications to produce a second set of coating parameters;

(f) designating the second set of coating parameters for use in coating a second workpiece; and

(g) repeating (c) – (f) for subsequent workpieces in the series until the identified set of discrepancies falls within a selected tolerance.

10. The method of claim 9, further comprising, after (g), designating the most recently-produced set of coating parameters for use in coating subsequent workpieces.

11. The method of claim 9 wherein each workpiece is a silicon wafer.

12. The method of claim 9 wherein the coating material is a conductor.

13. The method of claim 9 wherein the coating material is copper.

14. The method of claim 9 wherein the process is performed in an electrolysis chamber having a plurality of anodes, and wherein at least a portion of the coating parameters are currents to transmit through identified anodes among the plurality of anodes.

15. The method of claim 9 wherein at least a portion of the attributes of the coating layer to be produced on the workpieces specified by the coating profile are target thicknesses of the coating layer in selected regions on the workpiece.

16. The method of claim 15 wherein the discrepancies identified in (c) correspond to differences between thicknesses measured in the selected regions on the coated workpiece and the target thicknesses specified by the coating profile for the selected regions on the workpiece.

17. The method of claim 15, further comprising:

generating a set of predicted coating thicknesses in the selected regions on the first workpiece based upon the first set of coating parameters;

receiving an indication of thicknesses measured in the selected regions on the coated first workpiece;

computing a difference between the predicted coating thicknesses and the indicated measured thicknesses; and

subtracting the computed difference from the determined first set of modifications before using the first set of modifications to modify the first set of coating parameters.

18. The method of claim 15 wherein each of the workpieces bears a seed layer,

the method further comprising:

for each the first and second workpieces, receiving an indication of seed layer thicknesses measured in the selected regions on the workpiece before the workpiece is coated; and

before designating the second set of coating parameters for use in coating a second workpiece, further adjusting the second set of coating parameters in to adjust for differences between the measured thicknesses of the first and second workpieces.

19. The method of claim 9 wherein the coating process is electrolytic deposition.

20. The method of claim 9 wherein the coating process is electrophoretic deposition.

21. The method of claim 9 wherein the coating process is chemical vapor deposition.

22. The method of claim 9 wherein the coating process is physical vapor deposition.

23. The method of claim 9 wherein the coating process is electron beam atomization.

24. The method of claim 9 wherein the determining utilizes a sensitivity matrix mapping changes in attributes to changes in coating parameters expected to produce those attribute changes.

25. A computer-readable medium whose contents cause a computing system to provide closed-loop control of a process for applying a coating material to a series of workpieces to produce a coating layer of the coating material by:

(a) receiving a coating profile specifying one or more attributes of the coating layer to be produced on the workpieces;

(b) designating a first set of coating parameters for use in coating a first workpiece;

(c) identifying a first set of discrepancies between attributes of the coating layer produced on the first workpiece using the first set of coating parameters and the attributes specified by the coating profile;

(d) determining a first set of modifications to the first set of coating parameters expected to reduce the identified first set of discrepancies;

(e) modifying the first set of coating parameters in accordance with the determined first set of modifications to produce a second set of coating parameters;

(f) designating the second set of coating parameters for use in coating a second workpiece; and

(g) repeating (c) – (f) for subsequent workpieces in the series until the identified set of discrepancies falls within a selected tolerance.

26. A method in a computing system for automatically configuring parameters controlling operation of a deposition chamber to deposit material on each of a sequence of wafers to improve conformity with a specified deposition pattern, comprising:

for each of the sequence of wafers, measuring thicknesses of the wafer before material is deposited on the wafer;

for each of the sequence of wafers, measuring thicknesses of the wafer after material is deposited on the wafer;

for each of the sequence of wafers, configuring the parameters for depositing material on the wafer based on the specified deposition pattern, the measured thickness of the current wafer before material is deposited on the current wafer, the measured thickness of the previous wafer in the sequence before material is deposited on the previous wafer, the parameters used for depositing material on the previous wafer, and the measured thicknesses of the previous wafer after material is deposited on the previous wafer.

27. The method of claim 26 wherein the specified deposition pattern is a flat deposition pattern.

28. The method of claim 26 wherein the specified deposition pattern is a concave deposition pattern.

29. The method of claim 26 wherein the specified deposition pattern is a convex deposition pattern.

30. The method of claim 26 wherein the specified deposition pattern is an arbitrary radial profile.

31. The method of claim 26 wherein the specified deposition pattern is an arbitrary profile.

32. The method of claim 26, further comprising, for a second deposition chamber:

retrieving a set of offset values characterizing differences between the deposition chamber and the second deposition chamber;

modifying the parameters most recently configured for the deposition chamber in accordance with the retrieved set of offset values to obtain a parameters for the second deposition chamber; and

configuring the second deposition chamber with the obtained parameters for the second deposition chamber.

33. An apparatus for automatically configuring parameters controlling operation of a deposition chamber to deposit material on each of a sequence of wafers to improve conformity with a specified deposition pattern, comprising:

a pre-deposition measuring subsystem that measures thicknesses of each of the sequence of wafers before material is deposited on the wafer;

a pre-deposition measuring subsystem that measures thicknesses of each of the sequence of wafers after material is deposited on the wafer;

a parameter configuration subsystem that configures the parameters for depositing material on each of the sequence of wafers based on the specified deposition pattern, the measured thickness of the current wafer before material is deposited on the current wafer, the measured thickness of the previous wafer in the sequence before material is deposited on the previous wafer, the parameters used for depositing material on the previous wafer, and the measured thicknesses of the previous wafer after material is deposited on the previous wafer.

34. A method in a computing system for constructing a sensitivity matrix usable to adjust currents for a plurality of electrodes in an electroplating chamber to improve plating uniformity, comprising:

for each of a plurality of radii on the plating workpiece, obtaining a plating thickness on the workpiece at that radius when a set of baseline currents are delivered through the electrodes;

for each of the electrodes, for each of a plurality of plating workpiece radii, obtaining a plating thickness on the workpiece at that radius when the baseline currents are perturbed for that electrode; and

constructing a matrix, a first dimension of the matrix corresponding to the plurality of electrodes, a second dimension of the matrix corresponding to the plurality of radii, each entry for a particular electrode and a particular radius being determined by subtracting the thickness at that radius when the baseline currents are delivered through the electrodes from the thickness at that radius when the baseline currents are perturbed for that electrode, then dividing by the magnitude by which that the current for that electrode was perturbed from its baseline current.

35. The method of claim 34 wherein the current for each electrode is perturbed by approximately +.05 amps.

36. The method of claim 34 wherein the obtained thicknesses are obtained by executing a simulation of the operation of the electroplating chamber based upon a numerical model of the electroplating chamber.

37. The method of claim 34 wherein the obtained thicknesses are obtained by measuring workpieces plated in the electroplating chamber.

38. The method of claim 34, further comprising repeating the method to produce additional sensitivity matrices for a variety of different conditions.

39. The method of claim 34, further comprising using the constructed sensitivity matrix to modify for use in plating a second workpiece currents used to plate a first workpiece, such that the modified currents cause the second workpiece to be plated more uniformly than the first workpiece.

40. One or more computer memories collectively containing a sensitivity matrix data structure relating to a deposition chamber having a plurality of deposition initiators for depositing material on a workpiece having selected radii, a control parameter being associated with each of the deposition initiators, the data structure comprising a plurality of quantitative entries, each of the entries predicting, for a given change in the control parameter associated with a given deposition initiator, the expected change in deposited material thickness at a given radius,

such that the contents of the data structure may be used to determine revised deposition initiator parameters for better conforming deposited material thicknesses to a target profile for deposited material thicknesses.

41. The computer memories of claim 40 wherein the deposition initiators are electrodes, and wherein the control parameters associated with the deposition initiators are currents delivered through the electrodes.

42. The computer memories of claim 40 wherein the sensitivity matrix data structure is a Jacobian sensitivity matrix.

43. The computer memories of claim 40 wherein the computer memories contain multiple sensitivity matrix data structures, each adapted to a different set of conditions.

44. One or more computer memories collectively containing a data structure for controlling a material deposition process, comprising a set of parameter values used in the material deposition process, the parameters having been generated by adjusting an earlier-used set of parameters to resolve differences between measurements of a workpiece deposited using the earlier-used set of parameters and a target deposition profile specified for the deposition process,

such that the contents of the data structure may be used to deposit an additional workpiece in greater conformance with the specified deposition profile.

45. The computer memories of claim 44 wherein the deposition process utilizes a plurality of electrodes, and wherein each parameter value of the set is an amount of current to be delivered through one of the plurality of electrodes.

46. One or more computer memories collectively containing a deposition chamber offset data structure, comprising a set of values indicating how to adjust a first parameter set used to obtain acceptable deposition results in a first deposition chamber to produce a second parameter set usable to obtain acceptable deposition results in a second deposition chamber.

47. A reactor for electrochemically processing a microelectronic workpiece comprising:

a fluid chamber configured to contain an electrochemical processing fluid;

a plurality of electrodes in the fluid chamber;

a workpiece holder positionable to hold a surface of the microelectronic workpiece at an electrochemical processing fluid level in the fluid chamber;

one or more electrical contacts configured to electrically contact the surface of the microelectronic workpiece;

an electrical power supply connected to the one or more electrical contacts and to the plurality of electrodes, at least two of the plurality of electrodes being independently connected to the electrical power supply to facilitate independent supply of power thereto; and

a control system connected to the electrical power supply to control at least one electrical power parameter respectively associated with each of the independently connected electrodes, the control system setting the at least one electrical power parameter for a given one of the independently connected electrodes based on one or more user input parameters and a plurality of predetermined sensitivity values, the predetermined sensitivity values corresponding to process perturbations resulting from perturbations of the electrical power parameter for the given one of the independently connected electrodes.

48. The reactor of claim 47 wherein the at least one electrical parameter is electrical current.

49. The reactor of claim 47 wherein the sensitivity values are logically arranged within the control system as one or more Jacobian matrices.

50. The reactor of claim 47 wherein the at least one user input parameter comprises the thickness of a film that is to be electrochemically deposited on the at least one surface of the microelectronic workpiece.

51. The reactor of claim 47 wherein the independently connected electrodes are arranged concentrically with respect to one another.

52. The reactor of claim 47 wherein the independently connected electrodes are disposed at the same effective distance from the at least one surface of the microelectronic workpiece.

53. The reactor of claim 52 wherein the independently connected electrodes are arranged concentrically with respect to one another.

54. The reactor of claim 47 wherein at least two of the independently connected electrodes are disposed at different effective distances from the surface of the microelectronic workpiece.

55. The reactor of claim 54 wherein the independently connected electrodes are arranged concentrically with respect to one another.

56. The reactor of claim 55 wherein the independently connected electrodes are arranged at increasing distances from the surface of the microelectronic workpiece from an outermost one of the plurality of concentric anodes to an innermost one of the independently connected electrodes.

57. The reactor of claim 47 wherein one or more of the independently connected electrodes is a virtual electrode.